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BENEFITS AND COSTS OF MODIFYING PLAYA LAKES TO REDUCE ENCEPHALITIS IN THE TEXAS HIGH PLAINS

Herbert W. Grubb, et al

International Center for Arid and Semi-Arid Land Studies
Lubbock, Texas

February 1968

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Herbert W. Grubb
Don L. Parks
George W. Sciple

Department of Agricultural Economics
Texas Technological College
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BENEFITS AND COSTS OF MODIFYING PLAYA LAKES TO REDUCE ENCEPHALITIS IN THE TEXAS HIGH PLAINS

Herbert W. Grubb, Don L. Parks, and George W. Sciple [1/]

INTRODUCTION

The 36,000 square mile High Plains regions of northwestern Texas contains approximately 16,700 shallow, undrained, depressions. During periods of precipitation, run-off accumulates in these depressions and forms playa lakes. The lakes range in surface size from less than one acre to more than 100 acres and range in depth from a few feet to more than 20 feet. During the summer months, the shallow, warm, plant infested unmodified lakes are excellent breeding places for many kinds of mosquitoes including the species Culex tarsalis, an encephalitis vector.[2]

With the virtual elimination of malaria and yellow fever in the United States, arthropod-borne encephalitides have become the most significant group of diseases transmitted by mosquitoes.[3] Although encephalitis infections are relatively new from the standpoint of definite knowledge, these infections have probably existed for centuries.[4]

On the Texas High Plains, encephalitis cases were reported in most of the years during the period 1940-54 and outbreaks in humans occurred

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[1]Associate Professor, Department of Agricultural Economics, Texas Technological College and Texas Agricultural Experiment Station; former Graduate Research Assistant, Department of Agricultural Economics, Texas Technological College; and formerly medical Ecologist.

[2]Harmston, Fred C., et al., "Mosquitoes and Encephalitis in the Irrigated Plains of Texas," Public Health Service, U. S. Department of Health, Education, and Welfare, Public Health Reports, Vol. 71, No. 8, Washington, D. C., 1956.

[3]Huddleston, Ellis W. and Virginia C. Riggs. "Studies of Playa Lakes in the High Plains of Texas." Texas Water Development Board, Report 10, Austin, Texas.

[4]Beadle, Leslie D., "Status of Mosquito-Borne Encephalitis in the United States." Public Health Reports, Public Health Service, U. S. Department of Health, Education and Welfare, Vol. 74, No. 1, pp. 84-90. January, 1959.

in 1952 and 1954 with 23 and 32 cases, respectively. The incidence of equine (horse) encephalitis ranged from three cases in 1942 to 26 cases in 1944, with 25 cases reported in 1952.[5] Since this period, epidemics of arboencephalitis have occurred at irregular intervals. The continued reoccurrence of epidemics has resulted in increased interest in medical, entomological, engineering, and economic investigations for determining the types of acute clinical illness produced, the after effects in humans, the types of viruses involved, the epidemiology of the disease, the ecologic factor involved, and the costs and benefits of playa modification measures designed to control the breeding of Culex tarsalis.

The major purpose of this study was to estimate playa modification costs and health benefits within a 27 county area of the Texas High Plains (Figure 1). The specific objectives were to:

(1) Present the known causes and effects of arthropod-borne encephalitis.

(2) Estimate costs of alternative playa modifications.

(3) Estimate health benefits from encephalitis control.

Information pertinent to estimating health benefits was obtained from records of local area hospitals, physicians, and public agencies involved in dealing with encephalitis. Playa modification cost data were obtained from local area modification experimental work and local area earth moving firms.[6] Health benefits were defined as the costs of treating encephalitis plus income lost by encephalitis patients.

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[5]Harmston, Fred C., et al., "Mosquitoes and Encephalitis in the Irrigated Plains of Texas." Public Health Service, U. S. Department of Health, Education and Welfare, Public Health Reports, Vol. 71, No. 8, Washington, D. C., 1956.

[6]Lubbock City-County Health Unit, "Multipurpose Modification of Playa Sinks," Project 29, Division of Water Supply and Pollution Control, U. S. Public Health Service, Lubbock, Texas, 1962.

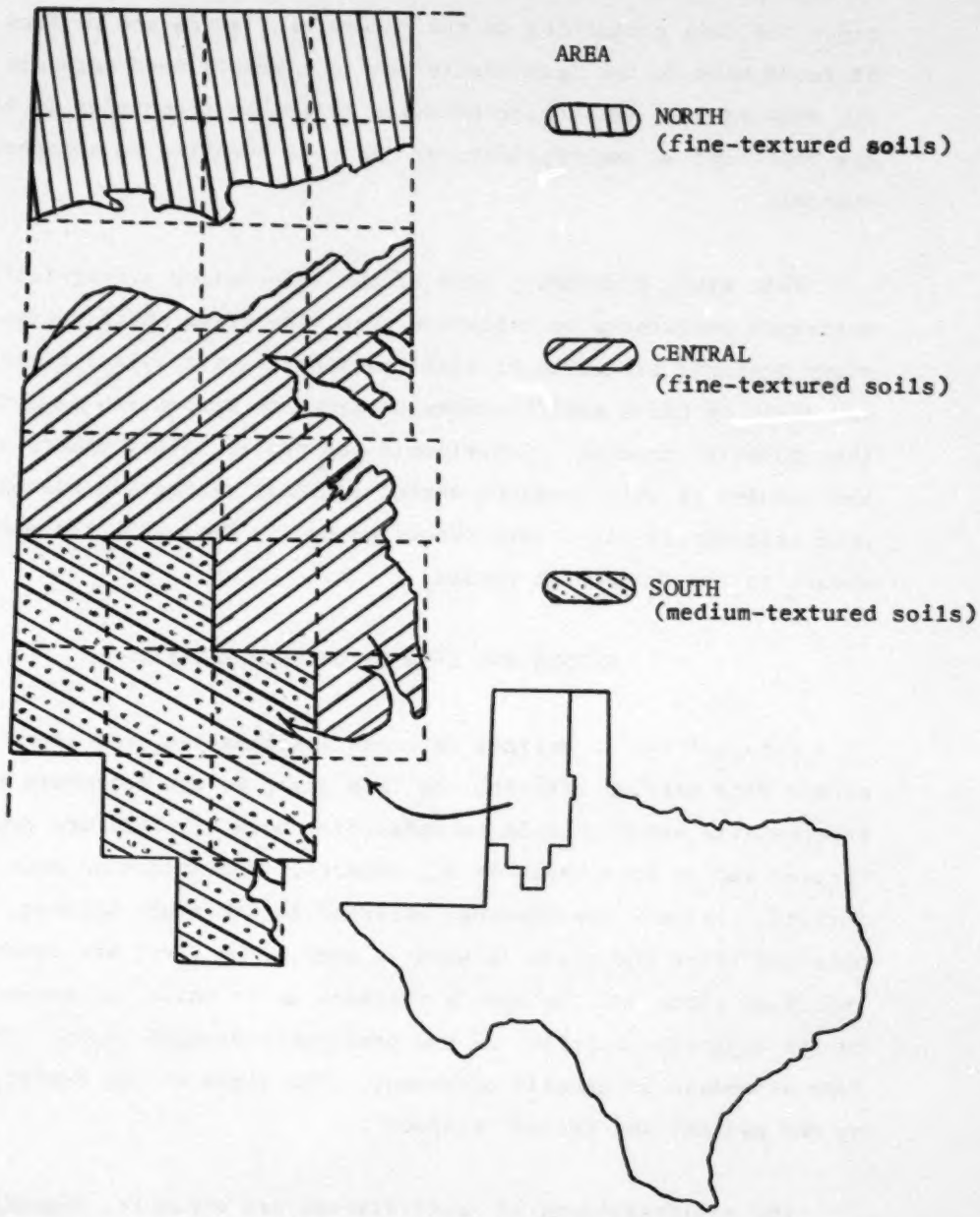

Figure 1. The Study Area

No attempt was made to evaluate human suffering caused by encephalitis since the data pertaining to the trauma of illness and perhaps death of loved ones do not lend themselves to commonly used economic measures. For this reason, the health benefits estimates undertaken in this study may represent an underestimate of the real benefits to encephalitis control.

This study provides a part of the information prerequisite to decisions pertaining to extensive area wide playa modification. A later study presents estimates of additional benefits to playa modification and costs of playa modifications designed to accomplish objectives other than mosquito control. Individuals and public policy makers will find the results of this research useful in their respective planning to utilize more effectively playa lake resources and to deal with the encephalitis menace to the Texas High Plains.

CAUSES AND EFFECTS OF ENCEPHALITIS

Encephalitis is defined as brain inflammation, and it may have many causes with varying effects. In this case, we are concerned with Western encephalitis and St. Louis encephalitis, both of which are caused by viruses and do have variable ill effects. A distinction must be made initially between the findings observed in the acute illness, and those observed after the acute illness is over. The first are caused by the infecting virus and the body's reaction to it while the second are related to the distorted function of the previously-damaged brain. This latter type of damage is usually permanent. The signs of the damage exhibited by the patient are termed "residus".

The manifestations of acute disease are variable, depending upon the severity of the individual patient's illness. They range from sudden feverish illness with convulsions and rapid death to mild sickness with

little more than headache and perhaps nausea. Fever, headache, and a sensation of being sick, termed "malaise", are common early signs and symptoms. These are non-specific, and occur in a great many diseases. Some or all of the following may be seen in severe cases: unconsciousness, convulsions, loss of the capacity to breathe spontaneously, rigidity of the muscles of the limbs, tremors (repeated shaking movements), failure of parallel movement of the eyes, incoordination of activity of major muscle groups, diminished intellectual ability, hallucinations, and personality changes. When these findings are present there is clinical evidence of brain inflammation, or "encephalitis" no matter what causative agent is involved. Milder cases may have only extreme headache, stiff neck, fever, nausea, and mild blurring of vision. Cases in persons who are minimally ill may show only slight fever, moderate headache, and muscle soreness. There is no clinical evidence encephalitis in these latter two milder pictures, no matter whether an "encephalitis" virus is causing them or not. Many persons who are naturally exposed to the virus, develop antibodies in their blood, showing that they were infected, and yet never have any recognizable signs of sickness. Therefore, viruses named "encephalitis" viruses may or may not give clinical evidence of causing brain inflammation or encephalitis in the literal sense. This confusion arose in the earlier days when it was believed that infection with these viruses always caused clinical encephalitis.

After-effects of Illness

Most people who have clinical illness with western encephalitis virus (WE) or St. Louis encephalitis virus (SLE) infection seem to recover completely, even though it may be three to six months or more before they return to their former sense of well-being. However, it is not known whether some of those who appear to recover completely may at a much later date show subtle evidence of brain damage.

Patients who are seriously ill in the acute phase frequently show evidence of persisting brain damage. These patients may never recover consciousness and may remain in a coma for extended periods. Convulsions may reoccur in brain-damaged persons long after the acute illness. Rigidity of the muscles of the body, once established in the acute phases of the illness may persist.

Tremors, especially of the hands, forearms, or tongue are among the more commonly seen residua, and these may be quite disabling. Mild personality changes, especially the tendency to become upset over minor happenings, are difficult to be certain about in most instances. They probably are fairly common. Severely damaged patients, especially infants, may be wholly dependent for the rest of their lives.

Types of Viruses Involved

Western encephalitis (WE) and St. Louis encephalitis (SLE) viruses are the only two arthropod (mosquitoes and other biting insect-like creatures) borne viruses known to cause human illness in the High Plains. It is possible that further study may uncover others. These two viruses are not distinguishable by the type of illness caused in the individual patient.

WE and WLE viruses are distinguishable in the laboratory. In an illness caused by either of these two agents, antibodies to the virus are formed and circulate in the patient's blood. These can be tested for by hemagglutination-inhibition, complement-fixation, and neutralization tests. For best diagnostic results, a blood specimen should be obtained from the patient on the first or second day of illness, another on the seventh to ninth day, and another at three to four weeks onset. Excellent testing facilities for such specimens are maintained at the Texas State Department of Health Laboratories.

Polio viruses, mumps virus, measles virus, "cold sore" (herpes simplex) virus and several other common viral agents can cause human illness indistinguishable clinically from that caused by WE and SLE viruses. The laboratory testing required to identify the virus or viruses causing cases is quite important. Public health control measures vary widely depending upon the type or types of viruses which are causing sickness in an outbreak. The testing can identify these agents. Measures designed to control mosquito-borne viruses obviously would not be applicable in an epidemic of sewerage borne polio-like viruses. If control measures are to be effective and economically feasible, they must be directed by the most complete and accurate information obtainable.

Epidemiology

Wild birds represent at present the major known reservoirs of both WE and SLE viruses, and high concentrations of either virus can circulate in the blood of small birds for several days after they are infected. Many birds show no obvious signs of sickness at times when one or the other of these viruses is present in their blood. Neither of these viruses is primarily a human virus. Both viruses seem to persist in nature without having to pass through a human host. In fact, humans seem to be involved in both WE and SLE infection in only an indirect manner. Horses probably are much like humans in this respect. There probably is no horse to horse or human to human direct transmission, nor any significant infection of blood feeding insect vectors when they attack sick humans or sick horses. Both humans and horses are, therefore, a "dead end" for either virus in terms of transmission beyond the sick individual.

A single species of mosquito, Culex tarsalis, seems to be the major vectos of both WE and SLE viruses in the High Plains region. This mosquito is a feeder on both birds and mammals. The following is believed to be the usual sequence of events leading to the infection of human beings: a Culex tarsalis mosquito bites a bird (often a young bird or nestling) and picks up virus along with the blood meal; over a period of a number of days, this virus grows in quantity in the mosquito's body and is present in the salivary secretions; after digestion of the blood meal, the mosquito is ready to feed again; the mosquito feeds this time upon a human, and injects virus along with the saliva at the time of biting; this virus grows in the human body, and may or may not cause illness depending upon the adequacy of the body's response to it.

Both WE and SLE viruses are extremely difficult to find in birds, mosquitoes or other High Plains creatures during any but the usual warm weather transmission season. The means by which virus persists for year after year in the Llano Estacado or High Plains area is at present unknown, despite a great deal of effort expended in trying to find the answer.

Ecologic Factors

The data indicate that the presence of encephalitis in the High Plains depends - at the least - on the continued presence and interaction of birds, viruses, mosquitoes and humans. The presence of mosquitoes in any appreciable degree depends extensively upon a single factor, the presence and character of water.

The problem with water in the context of the discussion is how to use it most favorably for humans and least favorably for mosquitoes. Culex tarsalis breeds in shallow, isolated, small, moderately vegetated, warm bodies of water. Standing water in playas, irrigation ditches, tail water pools, and sewage ponds are the preferred habitat of the this creature. Great numbers may breed in a few favorable locations. Many favorable breeding areas may result in the creation of enormous number of mosquitoes of this species. Experiments have demonstrated that these mosquitoes disperse widely from the spots where they are reared, and that they can travel for a number of miles. For these, and other reasons, water management for mosquito control must be an area-wide rather than an individual practice.

COST OF MOSQUITO CONTROL THROUGH PLAYA MODIFICATION

Playa Lakes -- Physical Description

Number, size, and location of lakes

Playa lake-beds are located in the bottoms of the undrained watersheds of the High Plains and are distinguishable from surrounding soil area since lake-beds have a distinct heavy clay soil type. The surface of playa lake-beds is relatively flat and flows smoothly into the surrounding land surface. Therefore, lakes may exceed the lake-bed delineations during extremely wet seasons and fail to reach the lake-bed delineations during dry seasons. For purposes of analysis of this study, the highest contour encompassing lake-bed soils was used to establish the perimeter of the lake-beds. All surface size and lake volume estimates pertain to this concept of lake-beds.

An aerial photograph and topographic map analysis resulted in an actual count of 16,734 playa lakes in the study area. The greatest concentration of lakes per unit land area was in the northern part of the South area and the southern part of the Central area (Figure 2). The predominant lake size was less than five acres and the number of lakes in a size classification decreased as the surface size of lakes increased (Figure 3).

Volume of Lakes

Regression analysis, of a representative sample of lakes, was conducted for the purpose of establishing lake volume-area relationships pertinent to estimating modification costs. The sample size in the combined North and Central areas was 80. The sample size in the South area was 18. The volume-area relationships for lakes in the sub-areas were expressed by the following equations:

$$\log_e V_f = \underset{(0.24985)}{-0.97474} + \underset{(0.07671)}{1.36100} \log_e X \qquad (1)$$

$$\log_e V_m = \underset{(0.27866)}{-0.90866} + \underset{(0.15448)}{1.24771} \log_e X \qquad (2)$$

where:

V_f = lake volume in acre feet in the North and Central sub-areas,
V_m = lake volume in acre feet in the South sub-area, and
X = lake surface area in acres.

The estimated equations indicated that the lakes of the North and Central areas had larger volume per acre of surface area than lakes of the South area. In the South, the sample lake sizes did not range above 50 acres whereas in the North and Central region the sample lake sizes included ten lakes over 50 acres in size. Equation (1) presented above

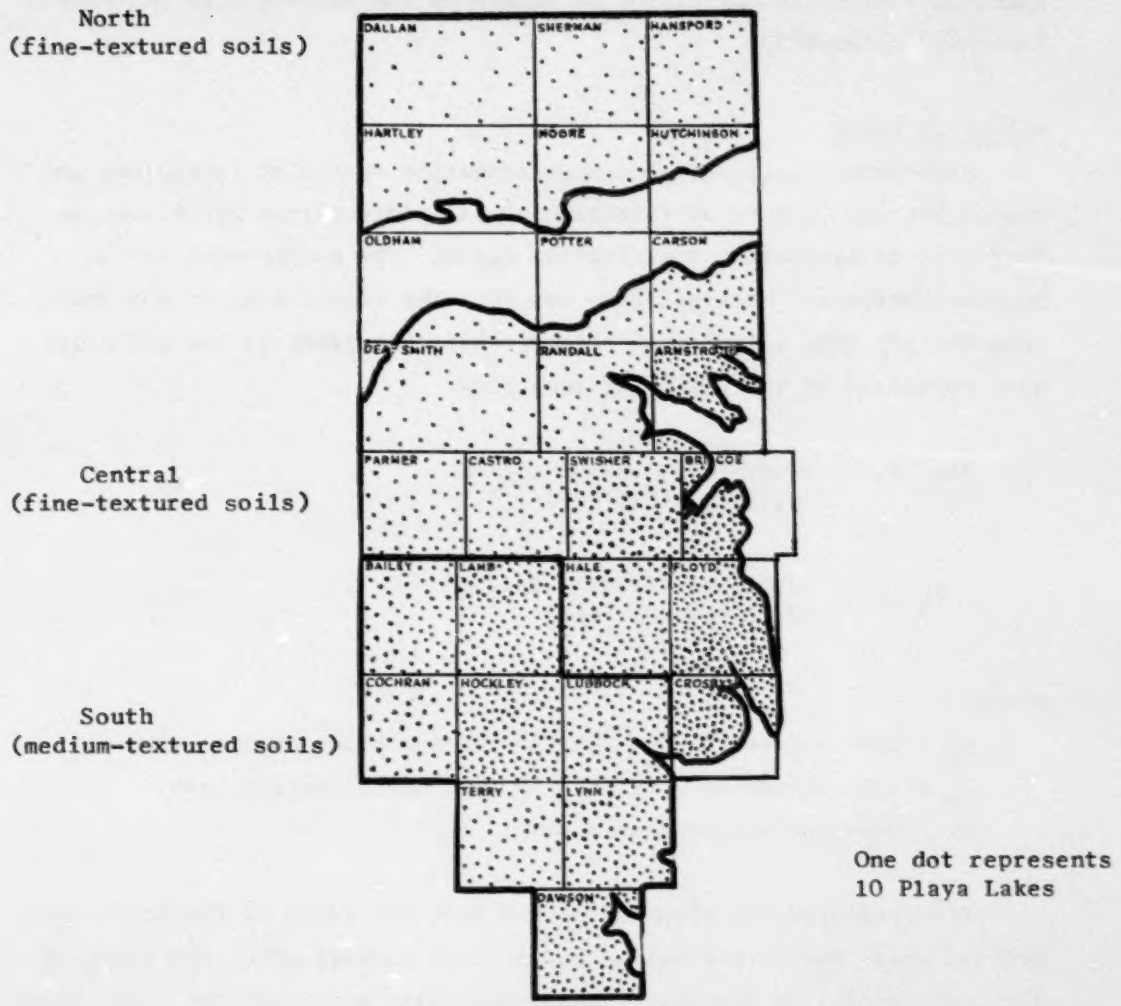

Figure 2: Playa Distribution by Counties; Texas High Plains

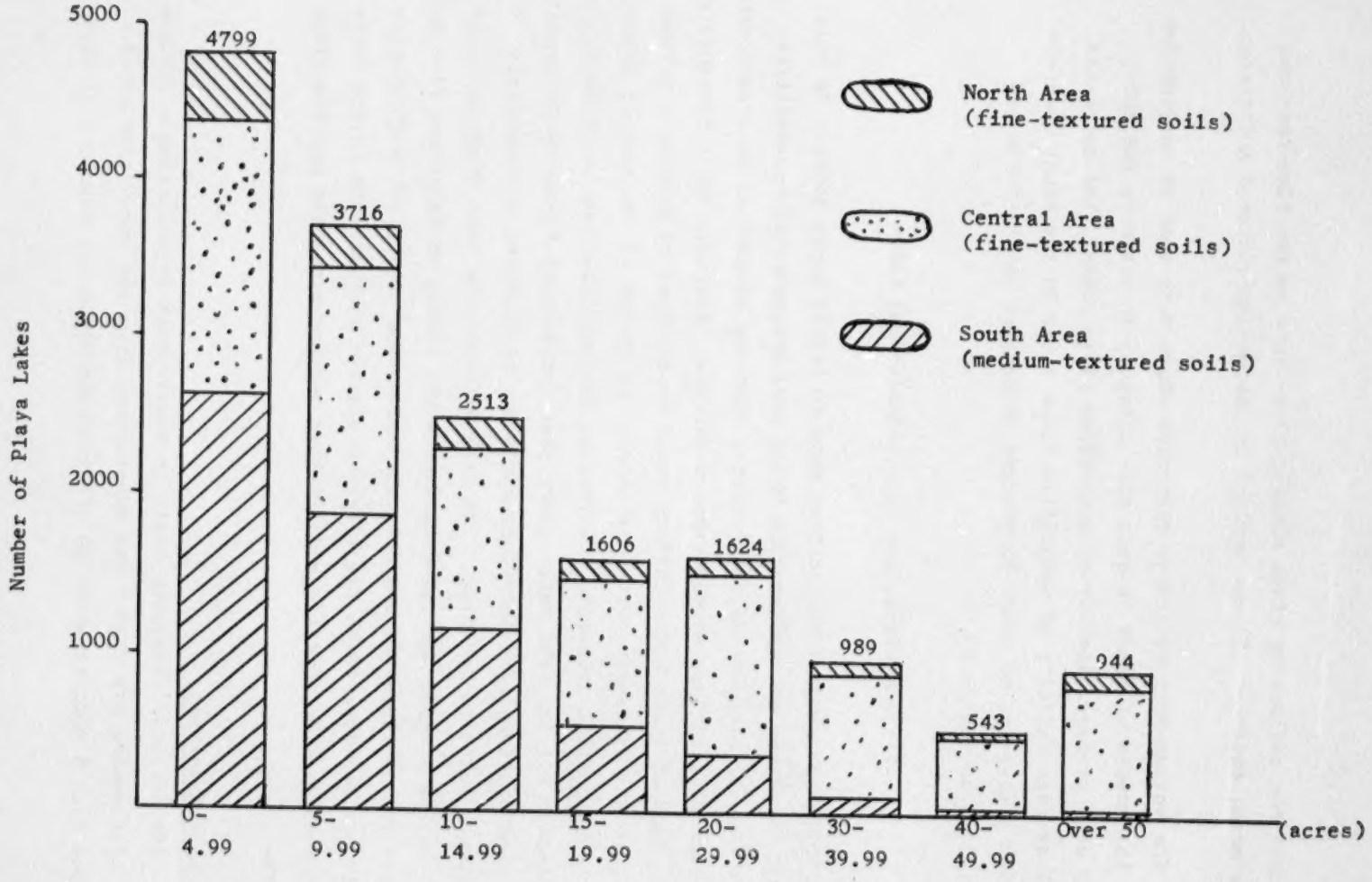

Figure 3: Number of Playa Lakes by Sub-Areas -- Texas High Plains

was used for estimating playa modification costs in the fine-textured soils area; equation (2) was applied to the medium-textured soils area.

The volume-area equations presented above were used in conjunction with the number of lakes in each size category to estimate the total study area storage capacity of unmodified playa lakes. The estimated total storage capacity of unmodified playa lakes in the study area was 365,122 acre-feet, of which 86 percent is located in the North and Central areas (Table 1).

Playa Modification Costs--Individual Lakes

There are several alternative ways to modify playa lakes. In this study, two types of modification which have demonstrated capabilities to reduce the breeding of encephalitis carrying mosquitoes were evaluated. The two modifications studied were a circular reservoir and a rectangular pit. Each of these modifications would be designed to contain a volume equal to the estimated volume of unmodified playas at the highest contour of the unmodified lake-bed. Neither of the modifications could be expected to contain all the lake water every year (occasional floods would overflow the modifications) and therefore could not be expected to completely eradicate mosquito breeding. The data available to this study indicate that on the average the modifications would likely be effective five out of six years. These data led to the assumption that playa modification could not be expected to completely eradicate encephalitis in the Texas High Plains. The specific modification designs evaluated are described below.

Circular Reservoir

The circular reservoir would be constructed by enclosing a shallow circular sunken pit with a dam constructed from the excavation spoil (Figure 4). A terrace would be construceted above the lake-bed perimeter

TABLE 1.--Estimated Storage Capacity of Unmodified Playa Lakes; Texas High Plains.

Area	Size in Acres								Area Total
	0-4.99	5-9.99	10-14.99	15-19.99	20-29.99	30-39.99	40-49.99	Over 50	
					(acre feet)				
North[a]	574	1,676	2,445	2,294	3,010	342	2,550	29,702[c]	42,953
Central[a]	2,269	9,101	13,221	17,649	34,344	37,635	31,134	128,483[c]	273,836
South[b]	3,312	9,347	11,059	7,550	8,579	4,318	1,911	2,617[d]	48,693
High Plains Total	6,155	20,124	26,725	27,493	45,933	42,295	35,595	160,802	365,122

[a]Storage capacity is computed using equation (1) in the text where x is average lake size in each size category and e is 2.7183. Estimated total volume is number of lakes times volume of the representative lake in each size category.

[b]Same as "a" above, using equation (2) of the text.

[c]Same as "a" above where X is 86.9 acres.

[d]Same as "b" above where X is 64.3 acres.

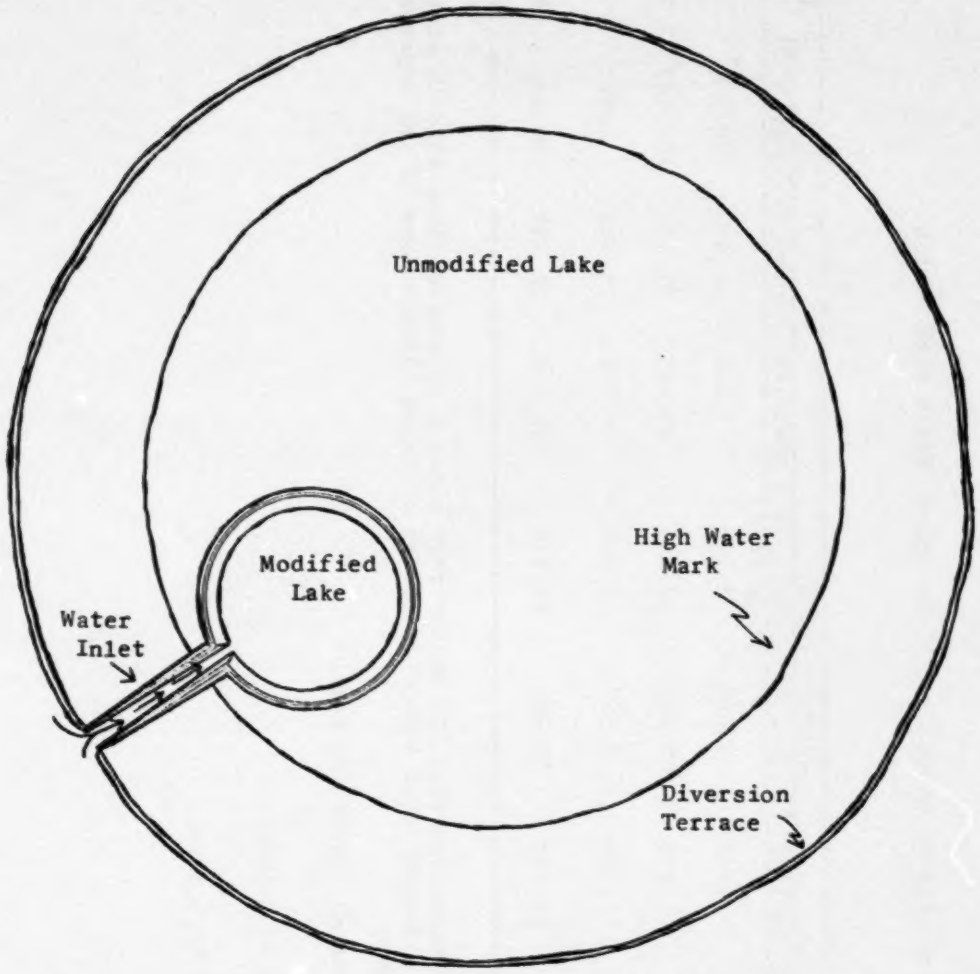

Figure 4: Circular Reservoir Modification

to divert run-off into the modified lake. The volume of earth moved (V_1) to construct this modification is expressed by the following formula:

$$V_1 = \frac{r^2 d + d^2 L}{27}$$

where

V_1 is volume of the pit, in cubic yards,

r is radius of sunken pit bottom, in feet,

d is depth of sunken pit in feet,

L is circumference of sunken pit in feet, where the radius is (r + 2h + 2 feet);

h is depth of water in feet, in the modified lake.

Water level in the modified lake would be two feet below the rim of the modification.

The volume of earth moved for the diversion system consists of the sum of the volumes for construction of the diversion terrace around the unmodified lake and the volume for the construction of the channel from the diversion terrace to the modified lake.

The volume of earth moved to construct the diversion terrace (V_{00}) is expressed as follows:

$$V_{00} = AL$$

where V_{00} is the volume, in cubic yards, of earth moved to construct the diversion terrace, A is cross sectional area, in square yards, of the diversion terrace, and L is length of the terrace in yards.

The number of cubic yards moved to construct the inlet channel to the circular reservoir modification is estimated as follows:

$$V_{01} = \frac{(a_1 + a_2) L}{27}$$

where:

V_{01} is soil volume, in cubic yards, of the two dykes that form the canal,

a_1 is cross sectional area, in square feet, the dyke end which connects to the terrace,

a_2 is cross sectional area, in square feet, the dyke end which connects to the reservoir;

L is distance, in feet, from diversion terrace to the reservoir

Estimates of the quantities of earth moved and earth-moving costs are presented in Table 2. Since the lakes of the South had smaller volumes per unit surface size, modification cost estimates are lower in the South area than in other areas.

Rectangular Pit

The rectangular pit modification is constructed by excavating a rectangular pit in the bottom of the unmodified lake (Figure 5). Part of the excavated soil is used to construct a dyke around the lake and the remainder is spread evenly over the unmodified lake-bed. Run-off is channeled into the modification through the dyke via a paved inlet flume.

The volume of earth moved in the construction of the rectangular pit modification equals the desired water volume of the pit; i.e., one cubic yard of earth removed creates one cubic yard of storage.[7] The volume (V_2) is expressed by the following formula:

$$V_2 = \frac{(LW) + (L'W')}{2} \quad \frac{h}{27}$$

where

V_2 is volume of the pit, in cubic yards,

[7]The pit specifications were designed to have the following characteristics, (1) a surface equal to one-tenth of the unmodified lake area and (2) end slopes of 6:1 with side slopes of 1:1.

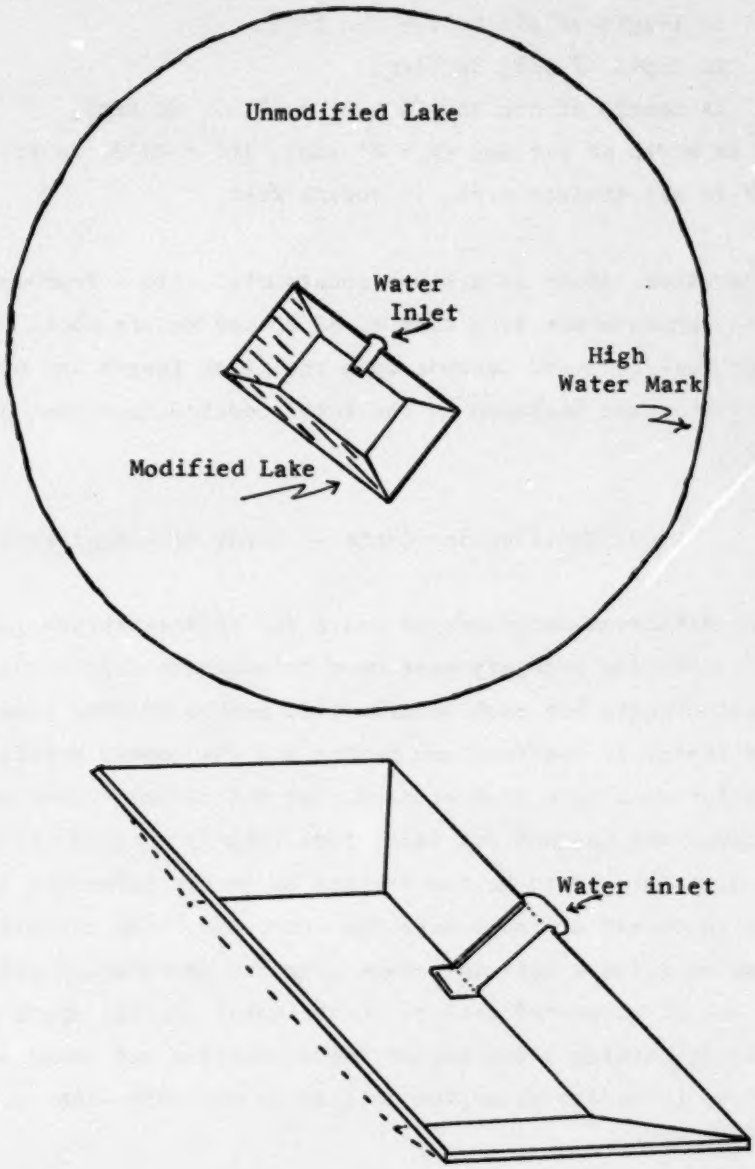

Figure 5: Rectangular Pit Modification

W' is width of pit bottom, in feet,
L' is length of pit bottom, in feet,
h is depth of pit, in feet,
L is length of pit top (L = L' + 12 h), in feet,
W is width of pit top (W = W' +2h), (L' = 4W'), in feet,
LW is pit surface area, in square feet.

The water intake is a flume constructed with a four-inch layer of asphaltic concrete mix at a cost of $0.50 per square foot. The number of square feet required depends upon the flume length and width. The intake cost estimates are included in the total construction cost of the modification (Table 2).

Playa Modification Costs -- Study Area Aggregated

The estimated modification costs for representative lakes in each relevant lake size category were used to estimate total study area lake modification costs for each modification method studied (Table 3). The circular reservoir modification method had the lowest modification cost estimate for each lake size studied, but the circular reservoir modification could not be used for lakes less than five acres since lake basins of this size lake would be too shallow to permit effective use of diversion terraces to direct drainage into the reservoir. The circular reservoir modification gains a cost advantage over the rectangular pit modification through use of excavated soil to create water storage space above lake-bed level by forming a dam around the excavation and consequently does not incur costs to spread excavated soil as is the case with the rectangular pit modification.

According to this study, the estimated cost of modifying playas, using the circular reservoir methods for lakes greater than five acres in surface size and the rectangular pit method for lakes less than five

TABLE 2.--Estimated Modification Requirements and Costs of Playa Modification per Lake by Modification Methods for Selected Lake Sizes; Texas High Plains, 1967.

Area	Lake Size	Circular Reservoir			Rectangular Pit		
		Earth Moving		Modification Costs per Lake[a]	Earth Moving		Modification Costs per Lake[b]
		Lake	Diversion and Inlet Channels		Lake	Inlet Flume	
	(acres)	(cubic yards)		(dollars)	(cubic yards)	(sq. ft.)	(dollars)
North plus Central	2.5	NA	NA	NA	2,097	90	590
	8.0	2,859	3,363	1,368	10,309	230	2,795
	15.0	5,236	4,585	2,161	24,941	364	6,666
	25.0	8,653	7,504	3,555	50,013	522	13,264
	45.0	15,239	13,134	6,242	108,254	890	28,591
South	2.5	NA	NA	NA	2,097	90	590
	8.0	2,402	2,751	1,134	8,712	230	2,380
	15.0	4,884	3,628	1,872	19,037	364	5,131
	25.0	6,017	6,818	2,864	36,139	522	9,657

NA = not applicable

[a]Cost calculated at $0.22 per cubic yard

[b]Cost calculated at $0.26 per cubic yard plus $0.50 per square foot of inlet flume. The pit modification requires spreading the excavated soil over the lake bottom, thus the higher modification cost.

TABLE 3. -- Present Worth of Estimated Playa Modification Construction and Maintenance Costs by Lake Size Distribution and Alternative Methods of Modification: Texas High Plains Area, 1967.

Area	Lake Size (acres)	Number of Lakes	Construction Costs per Lake		Total Area Construction Costs[a]		Present Worth of Construction plus Maintenance[b]			
							20 Years		40 Years	
			Circular Reservoir	Rectangular Pit	Circular Reservoir	Rectangular Pit	Circular Reservoir	Rectangular Pit	Circular Reservoir	Rectangular Pit
			(dollars)				(million dollars)			
North plus Central	0-5	2,170	NA[c]	590	NA[c]	1.3	NA	2.0	NA	2.2
	5-10	1,839	1,368	2,795	2.5	5.1	4.0	8.1	4.4	9.0
	10-20	2,417	2,161	6,666	5.2	16.1	8.2	25.3	9.1	28.2
	20-30	1,241	3,555	13,264	4.4	16.5	6.9	25.9	7.7	28.9
	30+	2,272	6,242	28,591	14.2	65.0	22.3	102.3	24.9	113.9
TOTAL		9,939	NA	NA	26.3	104.0	41.4	163.6	46.1	182.2
South	0-5	2,629	NA	590	NA	1.5	NA	2.4	NA	2.7
	5-10	1,877	1,134	2,380	2.1	4.5	3.3	7.1	3.7	7.8
	10-20	1,702	1,872	5,131	3.2	8.7	5.0	13.7	5.6	15.3
	20+	587	2,864	9,657	1.7	5.7	2.7	8.9	3.0	10.0
TOTAL		6,795	NA	NA	7.0	20.4	11.0	32.1	12.3	35.8
AREA TOTALS		16,734	NA	NA	33.3	124.4	52.4	195.7	58.4	218.0

[a] Modification costs included only the costs of earth moving and water intake constructions.

[b] It was assumed that maintaining the modifications original degree of usefulness would require an average annual investment of five percent of the original construction cost. A discount rate of six percent was used in calculating present worth of future maintenance cost. This rate of discount was chosen to reflect the opportunity income lake owners would forego if investment funds were used in playa modification instead of other investment alternatives.

[c] The reservoir was assumed to be non-applicable to less-than-five-acre lakes because lake basin depths were so shallow diversion terraces would be ineffective for draining the water into the reservoir.

acres in surface size, was $36 million. This is $88 million less than the estimated cost of modifying all playas using the rectangular pit method. At 6 percent per annum discount rate, the present worth of the combined construction outlay and annual maintenance cost for a 20 year period was estimated at $56.8 million (Table 3). For a 40 year period, present worth of construction costs plus annual maintenance was estimated at $63.3 million. In order to be justified from an economic standpoint, the present worth of future benefits from playa modification must equal or exceed present worth of modification costs; i.e., if playa modifications last 20 years, the future benefits stream must have a present worth of $56.8 million or if modifications last 40 years the future benefits stream must have a present worth of $63.3 million in order for playa modification to be economically feasible.

HEALTH BENEFITS FROM ENCEPHALITIS CONTROL THROUGH PLAYA MODIFICATION

It has been estimated that about three-fourths of total mosquito production in the study areas was from non-cultivated playas (playas having native vegetation) and the predominant mosquito species was Culex tarsalis -- the primary encephalitis vector.[8] It has been demonstrated that concentrating lake water into a pit with steep side slopes can reduce vegetation growth within lakes and thereby effectively reduce breeding of the mosquitoes which are the only known transmitters of arboencephalitis viruses to humans in this area.[9] A reduction in Culex tarsalis numbers is expected to result in a reduction in arthropod-borne encephalitis within the study area.

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[8]Harmston, Fred C., et al., "Mosquitoes and Encephalitis in the Irrigated Plains of Texas," Public Health Service, U. S. Dept. of Health, Education, and Welfare, Public Health Reports, Vol. 71, No. 8, Washington, D. C. 1956.

[9]"Second Annual Progress Report, Multipurpose Modification of Playa Sinks," Project 29, Division of Water Supply and Pollution Control, U.S. Public Health Service, Lubbock City-County Health Unit, Lubbock, Texas, 1963.

Annual health benefits from encephalitis control were estimated from historic medical costs to encephalitis patients of the study area. Total health benefits were expressed as present worth of the future stream of annual health benefits expected from playa modification for the purpose of comparing playa modification benefits and costs.

Encephalitis illness results in direct medical expenses to individuals, indirect medical expenses incurred to care for permanently disabled victims of encephalitis, lost income from temporary illness and losses of future expected income of permanently disabled and of deceased encephalitis patients. Eradication of arthropod-borne encephalitis would result in direct dollar benefits to study area residents in the amount of medical expenses saved plus the income that would have been lost as a result of encephalitis illness. There are additional economic benefits to projects which accomplish arbo-encephalitis control; i.e., the effects upon incomes elsewhere in the general economy due to changes in expenditures by individuals ill from encephalitis. The analyses of this study included only the medical costs and potential income losses in the benefits estimates. Data were not available with which to estimate the extended impacts of these arbo-encephalitis costs upon the general economy.

The average annual number of confirmed encephalitis cases in the study area during the period 1957-1966 was 24.5 cases (Table 4). Texas State Health Department records indicate that approximately 85 percent of encephalitis cases recover with no obvious after-effects after approximately 20 days of medical care, which includes hospital care plus recuperation after discharge from the hospital. The estimated average medical costs, per case, for these non-severe High Plains encephalitis patients was $314 (Table 5). In addition to diagnostic and treatment costs, encephalitis patients incurred an estimated expense of $75 per case for an after-effects test. No data were available for determining

TABLE 4. -- Confirmed Encephalitis Cases--Texas High Plains: 1957-1966[a]

County	Number of Cases										
	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	Total
Bailey	0	1	2	9	0	2	0	0	0	0	14
Briscoe	0	0	0	0	0	0	0	0	0	0	1
Castro	0	0	3	4	0	0	1	0	0	0	8
Crosby	0	0	7	0	1	0	4	1	1	2	16
Floyd	0	2	0	0	0	0	1	0	1	0	4
Garza	0	2	1	1	0	0	0	0	0	0	4
Hale	0	12	1	14	6	1	26	31	10	10	111
Hockley	0	0	0	1	1	0	0	0	0	0	2
Hutchinson	NA	NA	NA	NA	NA	NA	9	1	0	0	1
Lamb	0	0	5	3	1	0	3	0	0	3	15
Lubbock	0	5	7	8	8	3	5	3	1	5	45
Lynn	0	0	0	0	0	0	1	0	0	0	2
Parmer	0	0	0	1	0	0	0	0	0	0	1
Potter	NA	NA	NA	NA	NA	NA	0	3	9	0	12
Randall	NA	NA	NA	NA	NA	NA	0	0	1	0	1
Swisher	0	0	4	1	0	0	1	2	0	0	8
TOTAL	0	23	30	42	17	6	42	41	24	20	245

[a]Source -- The Texas State Health Department, Austin, Texas.

TALBE 5 -- Average Medical Costs to Hospitalized Encephalitis Patients[a]

Medical Costs	Age Category in Years		
	less than 6	6 - 39	40 or more
Hospital			
Room and Nursing	99.14	94.77	134.25
Medication	59.60	48.48	30.58
Laboratory Tests	40.59	44.88	74.96
Electroencephaliogram, X-ray, and electrocardiogram	5.54	16.73	41.87
Oxygen and equipment	54.60	10.09	4.70
Physical therapy	2.14	1.15	0.00
Miscellaneous	20.79	4.93	13.30
Physician	71.17	89.44	99.55
Total Costs	342.57	310.47	399.21
Total cases	14	13	4

[a]Calculated from 1964-65 records of the Plainview Hospital and of Plainview physicians; Plainview, Texas.

the cost of medication for after-effects; thus the resulting benefits estimates are an under estimate by the amount of medication costs for after-effects of the disease upon the non-severe cases.

About 15 percent of encephalitis patients had extremely severe illness and high medical costs.[10] The persons affected were generally the very young (less than 2 years) and persons over 40 years of age. These more severe cases incurred higher medical costs because of longer hospitalization periods, special nursing requirements, the use of oxygen, and increased physician and miscellaneous hospital costs. Many of these more severe cases resulted in costs of $2,000. The cost data show that it would be possible to incur costs that range into thousands of dollars if a patient were to lapse into coma and require special nursing and hospitalization for lengthy periods.

The data indicated that as the age of patients increased, there tended to be an increase in the total cost of room and nursing, lab work, the physician's services, and a decrease in the medication cost, oxygen cost, and physical therapy cost (Table 5). The average total cost to patients appeared to be lowest for patients in the six to 39 year age group and highest among patients over 40.

On the basis of the above estimates pertaining to average number of cases per year, areawide direct medical costs of non-severe cases were estimated at $9,531 per year. These medical cost estimates do not include nursing care and other costs incurred after dismissal from the hospital. There were no data available to this study with which to estimate these costs. Thus the medical costs estimates of this study may be an under-estimate of areawide actual costs.

The indirect costs of encephalitis in the study area included the costs of caring for patients mentally retarded as a result of encephalitis, income

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[10] Estimated from a 50-case sample of severe encephalitis cases in Hale Center, Texas during the period 1952-66.

losses to patients during illness, and present value of future income expected by permanently disabled and deceased encephalitis patients. Encephalitis patients who were less than two years of age had a high probability of permanent brain damage. Eight confirmed cases of patients under two years of age in Hale County in 1964 were all severely retarded. It was not known if they can be educated or trained to care for themselves. If these patients are non-trainable, they will likely become patients in a state hospital at a public expense of $10 to $12 thousand per person annually, and in addition would become a further loss to society by involuntarily leading non-productive lives. The data pertaining to the number of permanently disabled encephalitis patients from the study area presently located in institutions are insufficient to permit precise evaluation of this cost of encephalitis. Available data pertaining to number of new cases of encephalitis resulting in permanent brain damage indicates that there would be an average annual number of 10 patients under care and that each patient would receive care for a period of 20 years. Under these conditions, one new encephalitis patient from the study area would be admitted to a state hospital each two-year time period. Based on the above information, the estimated annual public expense of caring for permanently disabled encephalitis patients of the study area would be $100,000 (10 patients x $10 thousand per patient). Estimates of income foregone by encepahlitis patients were calculated as follows:

1. The estimated income lost by males normally employed but temporarily prevented from working for the estimated average 20 days of rest associated with an encepahlitis case was $2,759. This estimate was based on national average annual income for males 14 years and over ($6,949).[11] The

[11] Public Health Service, Estimating the Cost of Illness, Health Economics Series No. 6, U. S. Dept. of Health, Education and Welfare, Public Health Service Publication No. 947-6, Washington, D. C. 1966.

encephalitis data for the study area showed that 34.8 percent of the average annual 20.8 non-severe encephalitis cases in the Texas High Plains were males over 14 years of age.

2. The national average annual income of females was $4,207. The estimated income lost by females normally employed but temporarily prevented from working because of encephalitis was $570. The estimated annual number of non-severe encephalitis cases in the study area that were females was 4.9.

3. The number of patients each year who were permanently disabled plus the number of deceased patients was estimated at 15 percent of the average annual number of encephalitis patients. This estimate was based on the proportion of disabled and deceased patients as shown by the Hale County data. Data pertaining to deaths and disability from encephalitis were not available for the remainder of the study area.[12] The Hale County statistics on number of permanently disabled plus deceased encephalitis patients were assumed to be representative of the study area. When projected to the total Texas High Plains study area, the Hale County data yielded an area estimate of $118 thousand in present worth of future income losses by those patients who would be permanently disabled and deceased annually (Table 6). For example, it was estimated that on the average, there would be 3.7 cases per year (15 percent of total cases per year) that would be either permanently disabled or deceased from encephalitis. Incomes expected by each sex and age group, were used in calculating the estimate of present worth of incomes (benefits) for the estimated 3.7 permanently disabled or deceased patients of one year. Playa modification to reduce encephalitis would be expected to

[12]Estimated from data on actual cases during the 1963-65 period.

TABLE 6.--Present Worth of Future Income Losses by Individuals Permanently Disabled and Deceased from Encephalitis Annually; Texas High Plains.[a]

Age (years)	Sex	Average Annual Number of Cases	Present Worth of Lost Income[c] (1000 dollars)
Less than 1	Male	0.93	28
	Female	1.83	33
1 - 4	Male	0.11	4
	Female	0.24	9
Over 4[b]	Male	0.59	44
	Female	0.00	0
TOTAL		3.7	118

[a]Arbo-encephalitis case statistics for the period 1957-1966.

[b]Ages of actual cases were 5, 21, 28, 43, and 52 years.

[c]Present value of expected future earnings of persons in each age group calculated at 6 percent discount rate (Appendix B, Table C).

produce benefits during the future years of useful life of the modifications, therefore, the benefits to playa modification are the present worth of an annual benefits stream; i.e. in this case the present worth of a $118 thousand annual benefit.

Average annual indirect cost of arbo-encephalitis was estimated at $221 thousand (Table 7). Estimated annual total costs of arbo-encephalitis in the study area was $234 thousand. Total encephalitis costs cannot be claimed as health benefits to playa modification, however, since some encephalitis spreading mosquitoes would be bred within the study area in water tanks and perhaps other water containing devices. Playa modifications would also be expected to overflow, upon occasion of heavy precipitation, and create favorable mosquito breeding conditions. With estimated annual encephalitis costs adjusted for nonlake produced mosquitoes and flooding of playa modifications the annual health benefits to playa modification was estimated at $147 thousand. If playa modifications have a life expectancy of 40 years, present worth of future annual health benefits of $147 thousand. If playa modifications have a life expectancy of 40 years, present worth of future annual health benefits of $147 thousand would be $2.21 million(Table 7).

The combined North and Central subareas of the study area reported 66.5 percent of the confirmed cases of encephalitis on the Texas High Plains; thus the portions of the estimated health benefits to playa modification accruing to the North and Central subareas (fine-textured soil) were estimated at $1.12 million if the modifications last 20 years and $1.47 million if the modifications have a 40 year life. For the South subarea (medium-textured soil) benefits were estimated at $0.56 million if the modifications last 20 years and $0.74 million if the modifications last 40 years.

TABLE 7.--Estimated Health Benefits to Playa Lake Modification - Texas High Plains

Item	Benefits[a]		
	Annual	Present Worth of 20-Year Benefit Stream	Present Worth of 40-Year Benefit Stream
DIRECT			
Medical Care[b]	13,353	153,158	200,913
INDIRECT			
Lost Income (disabled plus deceased)[c]	118,000	1,353,448	1,775,463
Lost Income (males temporarily unemployed)	2,759	31,645	41,513
Lost Income (females temporarily unemployed)	570	6,537	8,576
Institutional Care Costs (permanently disabled patients)[d]	100,000	1,147,000	1,504,630
TOTAL INDIRECT COSTS	221,329	2,538,630	3,330,182
BENEFITS (Total Health Costs)	234,682	2,691,788	3,531,095
BENEFITS ADJUSTED (nonlake mosquitoes)[e]	176,011	2,018,841	2,648,321
BENEFITS ADJUSTED (nonlake mosquitoes and modification flooding)[f]	146,617	1,681,694	2,206,051

[a]Calculated at 6 percent discount rate

[b]Hospital and after-effects cost for non-severe cases

[c]Present worth of future incomes of patients expected to be affected by encephalitis annually. Without modifications this cost can be expected to recurr on an annual basis.

[d]Ten cases per year at $10,000 per case.

[e]Modified playas are expected to reduce encephalitis cost by 75 percent; i.e., some encephalitis spreading mosquitoes would be bred in stock watering tanks, etc.

[f]The modifications are expected to be ineffective one year out of six; i.e., benefits would be reduced an average of 16.7 percent per year.

The decrease in municipal mosquito control cost resulting from playa lake modifications is a potential benefit to playa modification but data were not available with which to accurately estimate these benefits. It was noted that two High Plains cities had a combined annual mosquito control cost of $60 to $90 thousand; data were not available from other Texas High Plains cities.[13] The forgone expense of municipal mosquito control due to modifying lakes was not considered in this study.

MODIFICATION COST - HEALTH BENEFIT COMPARISONS

The estimates of this study show that the health benefits from playa modification in the Texas High Plains are not sufficiently large to make playa modification an economically feasible project (Table 8). Estimated health benefits undiscounted through time were positive but were only 5.1 percent of estimated modification costs if projects last 20 years and 9.2 percent of estimated costs if projects last 40 years. When future health benefits were discounted at 6 percent per annum, present worth of the health benefits were only 2.9 percent of modification costs for 20 year projects and 3.5 percent of modification costs if modification projects last 40 years.

Playa modifications would be multipurpose in that the modifications designed to reduce mosquito breeding would protect lake-bed cropland from flooding and would also be expected to reduce evaporation and thus save water for irrigation. Playa modifications would produce benefits additional to health benefits. It has been estimated that benefits, to farmers, of protecting lake-bed cropland from flooding and irrigation benefits to farmers from modification of lakes larger than ten acres would exceed modification costs in the fine-textured soils area. Individual farms of

[13] The county health unit of one of the larger cities of the study area reported a mosquito control budget of $40 to $60 thousand and a medium-size city reported a mosquito control cost of $20 to $30 thousand.

TABLE 8.--Modification Costs-Health Benefit Comparisons for Playa Lake Modification in the Texas High Plains.

Years of Useful Modification Life[a]	Construction Cost	Present Worth of Costs		Present Worth of Health Benefits	
		Maintenance Cost[b]	Total Cost	Zero Discount Rate	Six Percent Discount Rate
		(million dollars)			
20	36.1	20.7	56.8	2.93	1.68
40	36.1	27.2	63.3	5.86	2.21

[a]The life of modifications of the type studied is not known. Costs and benefits were calculated for both 20 and 40 years of modification life.

[b]Present worth of maintenance costs were calculated at a 6 percent discount rate.

of the fine-textured soils area would find it profitable to invest in modifications of the type considered in this study for lakes over 10 acres in size.[14] Estimated lake-bed land and water benefits for lakes smaller than ten acres in the fine-textured soils area and all lake sizes in the medium-textured soils area were less than estimated modification costs.

The combined estimates of health and lake-bed land and water benefits are not sufficient to completely offset estimated modification costs of lakes in the zero to 10 acres range of sizes in either soils area; i.e. present worth of modification costs for less than 10 acre lakes were estimated at $11.6 million if playa modifications last 20 years and $13.0 million if modifications last 40 years. Present worth of study area health benefits plus present worth of lake-bed land and water benefits from lakes in the zero to 10 acres size range were estimated at $5.38 million if modifications last 20 years and $7.01 million if modifications last 40 years. The ratio of benefits to costs when viewed this way was 0.46 if projects last 20 years and 0.54 if projects last 40 years.

According to estimates of lake numbers presented earlier, and cost-benefits estimates shown above, it would not be economically feasible to modify 10,813 (the number of lakes less than 10 acres in size plus larger lakes in the medium-textured soils area) or approximately 65 percent of the playas in the Texas High Plains by the modification methods considered in this study. Since the zero-ten acre lakes are widely scattered throughout the High Plains area, the failure to modify these small lakes would likely result in health benefits near the zero level, even though larger lakes of the fine-textured soils area may be modified; i.e. this many (65 percent), widely scattered and non-modified lakes would likely produce a sufficiently large number of encephalitis spreading mosquitoes, near enough to population centers, to continue the incidence of encephalitis in the High Plains area.

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[14] Grubb, H. W. and Parks, D. L., "Multipurpose Benefits and Costs of Modifying Playa Lakes of the Texas High Plains", Department of Agricultural Economics, Texas Technological College, Lubbock, Texas, February, 1968.

Since the analyses of this study show that the modification methods considered would not be economically feasible for lakes under 10 acres in either soils area and would not be feasible for larger lakes of the medium-textured soils area, it will be necessary to investigate additional ways of modifying small lakes to reduce mosquito breeding from which encephalitis benefits could be realized. It may be possible to connect a group of small lakes into one larger lake or to drain small lakes into near-by, larger, modified lakes either by gravity flow systems or by pumping water from one lake to another. The modifications considered in this study consisted of on-site modification; i.e. each lake would be modified to contain run-off of the lake within modifications in the lake-bed. The estimated cost per lake to construct a modification (rectangular pit) that would concentrate the water of small lakes into modification that would not produce mosquitoes was approximately at $600 per lake. The estimated cost of installing a sump and a lake pump to remove water from these small lakes before mosquito breeding could take place was $700 per lake. The estimated cost of water removal was greater per lake than the estimated cost of modifications to concentrate the water on site, and in addition would require labor, operating expenses, and management each time water were collected. Therefore, it appears that systems to drain small playas into larger lakes would need to be designed for gravity flow as opposed to pumping, if they are to be economically feasible. Extensive field studies would be required in order to obtain the data necessary to make an areawide economic evaluation of connecting several small playas into larger lakes. The cost-benefit methods of this study would be generally applicable to such an evaluation; i.e. the circular reservoir and the rectangular pit modifications would be relevant alternative modifications for a larger lake, but at present the data on the distance between lakes, the concentration of small lakes, the proximity of small lakes to larger lakes, and the costs of moving water between lakes are not adequate to permit an accurate area-wide economic evaluation of this alternative.

The benefit estimates of this study pertain to estimation of total study area potential health benefits from playa modification. Partial study area benefits could be realized if Culex tarsalis producing lakes near population centers were modified. However, the data with which to estimate the partial benefits are not available. For example, the distances mosquitoes travel and the distances of travel of virus infected hosts would need to be considered in order to determine the size of the area surrounding a population center, within which playa modification would be necessary, if encephalitis benefits were to be realized within the population center. These data are not available at present. In order to estimate partial study area benefits it would be necessary to conduct a detailed sub-area encephalitis cost analysis pertaining to each population center. At present, reliable data on encephalitis cases are available only on a county basis.

SUMMARY

The shallow warm water collected by the Texas High Plains playas provides excellent breeding places for Culex tarsalis, a mosquito which is a vector of encephalitis. Encephalitis cases were confirmed in the High Plains in nine of the past 10 years and encephalitis epidemics occurred in 1952, 1956, and 1964. The effects of the disease range from minor illness to permanent disability and death in a few cases.

It has been demonstrated that modification of the playas to concentrate the accumulated runoff water in deep small-surface size lakes will reduce the breeding of encephalitis spreading mosquitoes (Culex tarsalis). Modification of playas to accomplish mosquito breeding control can be expected to produce health benefits to the area through a reduction in the incidence of encephalitis.

The objectives of this study were to (1) present the known causes and effects of encephalitis, (2) estimate the costs of alternative playa modifications, and (3) estimate area-wide health benefits, from encephalitis control. The study area consisted of 27 counties located in the fine and medium-textured soils areas of the Texas High Plains.

Encephalitis is defined as a brain inflammation, and is caused by an infecting virus and the body's reaction to it. The disease may produce a sudden feverish illness with convulsions and rapid death or only a mild sickness with perhaps a headache and nausea. Most people who have clinical illness with the encephalitis strains found in the High Plains (Western and St. Louis) seem to recover completely even though it may be three to six months before they return to their former sense of well-being. Patients, who are seriously ill in the acute phase, frequently show evidence of persisting brain damage. These patients may never recover consciousness and may remain in coma for extended periods.

Wild birds represent at present the major known reservoirs of encephalitis viruses. The viruses seem to persist in nature without having to pass through a human host, and the human is thought to be a "dead-end" for the viruses in terms of transmission beyond the sick individual. Culex tarsalis seems to be the major vector of WE and SLE (Western and St. Louis) viruses in the High Plains. This mosquito is a feeder on both birds and mammals and is thought to transmit encephalitis viruses from birds to humans through its normal feeding habits. The viruses are difficult to find in birds, mosquitoes, and other High Plains creatures during any but the usual warm weather transmission season.

It was estimated that the study area had 16, 734 playa lakes with 9,939 located in the fine-textured soil area of the North and Central Plains and 6,795 located in the medium-textured soil area of the South Plains. The estimated total storage capacity of playa lakes of the study area was 365 thousand acre-feet of which 86.5 percent was located

in the fine-textured soil area. The fine-textured soil area had a larger number of large lakes and the lakes had larger volumes per unit surface size than lakes of the medium-textured soil area. Approximately 67 percent of confirmed encephalitis cases during the past 10 years were from counties of the fine-textured soils area.

The costs of two types of mosquito breeding control modifications were estimated for 2.5, 8.0, 15, 25, and 45 acres lakes in each soil area. One alternative modification consisted of a circular reservoir in the lake with a diversion terrace and an inlet channel to divert runoff water into the reservoir. The other modification was a rectangular pit excavated in the lake bottom with the excavated soil spread over the remaining portion of the lake bottom. Water would be diverted into the pit by means of a bank around the pit, which diverts runoff into a formless flume at one side of the pit. The circular reservoir method had lowest modification cost for lakes over five acres in size, but for technical reasons could not be used for lakes less than five acres thus the lowest modification costs were obtained when circular reservoirs were used for lakes over five acres and rectangular pits for lakes less than five acres. Construction costs of modifying playas in the study area using the modification combination mentioned above was estimated at $36 million. Present worth of construction and maintenance costs of modifying playas of the study area to effectively reduce encephalitis was estimated at $56.8 million if modifications last 20 years, and $63.3 million if modifications last 40 years.

The health benefits of playa lake modification are the reductions in expense of encephalitis. The expense of encephalitis is the sum of the direct cost of medical care and indirect cost which includes (1) the income lost by encephalitis patients (non-severe cases, permanently disabled patients and deceased patients) and (2) cost of caring for permanently disabled encephalitis patients.

The analysis indicated that the average annual number of encephalitis cases in the study area was 24.5 with an estimated average annual direct cost of encephalitis of $9,531 and an average annual indirect cost of $221 thousand. It was estimated that lake modification could be expected to decrease the number of encephalitis cases 75 percent for five out of six years. The average annual health benefits to the study area from lake modification were estimated at $146 thousand.

The expected benefits from playa modifications were evaluated at both 20 and 40 year expected life of modifications since it is not known at present how long playa modifications can be expected to last. The present worth of a 20 year stream of annual benefits, discounted at six percent, amounted to $1.68 million ($1.12 million in the fine-textured soils area and $0.56 million in the medium-textured soils area). The present worth of a 40 year stream of benefits was estimated at $2.21 million ($1.47 million in the fine-textured soils area and $0.74 million in the medium-textured soils area).

Estimated health benefits were only 2.9 percent of modification costs if modifications last 20 years, and 3.5 percent of modification costs if modifications last 40 years. On the basis of these estimates, health benefits from encephalitis are not sufficient to justify playa modification. A separate analysis of the benefits from lake-bed land protection and irrigation water savings shows that it would be profitable for farmers of the fine-textured soils area to modify playas over 10 acres in size on the basis of lake-bed land and water benefits. This same anlysis showed on the basis of land and water benefits, that it would not be profitable, to modify lakes under 10 cares in size in the fine-textured soils area and that it would not be profitable to modify playas of the medium-textured soils area. The estimated multipurpose benefits (health plus land plus water) were not large enough to offset playa modification costs in the medium-textured soils area or in the fine-textured soils area for lakes of less than 10 acres.

Approximately 50 percent of the lakes of the High Plains are smaller than 10 acres. Since these small lakes are widely scattered throughout the area, it is highly unlikely that encephalitis can be significantly reduced unless these small lakes are modified, even though larger lakes of the area may be modified for land protection and water saving purposes. The data on playa lake numbers show a significant number of playas in the zero to 10 acre size for each county, which means that without modification of the small lakes there would likely be a source of Culex tarsalis mosquitoes near enough to population centers to continue the incidence of encephalitis within the area.

Alternatives to the types of on-site modifications considered in this study are available, such as the drainage of small playas into larger lakes, the pooling of several small playas into one larger lake, and the filling of small lakes to produce a flat surface which would not collect water. On the basis of cost estimates available to this study, it would be necessary to design lake drainage systems to utilize gravity flow if such systems are to be economically feasible. The estimated cost of installing pumping equipment to remove the water was greater than the cost of the on-site storage facility which was not an economically feasible modification method for small lakes. Extensive field studies to obtain data on the distances water would have to be moved among lakes, the cost of constructing the systems, and the cost of filling small lakes with earth from the surrounding landscape would be necessary before an economic evaluation of these alternatives can be conducted.

The results of this study could become obsolete with changes in playa modification technology, changes in prices of modification inputs or outputs, and medical breaktrhoughs pertaining to encephalitis prevention or treatment. Major improvements could be made in the economic analysis of playa modification costs and benefits if better data were available about the runoff of playa watersheds in relation to watershed size and watershed use. At present, the data about costs of after-effects and

costs of caring for permanently disabled patients are not on record. Health benefit estimates could be improved if detailed records of costs of encephalitis treatment, including costs of after-effects and costs of care of permanently disabled patients were filed at a central point.

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Appendix A

METHODS AND PROCEDURE

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Data pertaining to the physical characteristics of playa lakes were obtained for the purpose of establishing estimates of the volume-area, volume-depth, and volume-time relationships, as well as the number and size of lakes in the fine- and the medium-textured soil areas. These physical data were necessary for calculating estimates of lake modification costs. Modifications with steeply inclined water perimeters have been found to eliminate mosquito breeding. Two ways of modifying playa lakes to meet mosquito abatement requirements were studied.

Physical Characteristics of Playa Lakes

Enumerating and Classifying Playa Lakes

The lakes were defined as that area of land covered by a Randall Soil Series and enclosed by a lake-bed contour line.[1] Using this definition of a playa lake, the lakes of each county were simultaneously counted and classified according to surface size from soil and topographic maps of the Soil Conservation Service and the United States Geological Survey. For counties which had not been completely mapped by the Soil Conservation Service or the United States Geological Survey, the percentage of the mapped area to the total county area was determined; this percentage was used to project the lake category counts of the county's mapped area to the total county area.

Lakes were classified on the basis of eight size categories. These size categories were on five acre intervals from zero to 20 acres, 10

[1]The lake-bed perimeter was defined as that elevation which was characterized by vegetative debris, changes in soil constitution, and changes in the nature and varieties of vegetation.

acre intervals from 20 to 50 acres, and included one interval of 50 acres or more.

Estimating Volume of Playa Lakes

Information was obtained on the shape of various size playas in the fine-and the medium-textured soil areas of the Texas High Plains, for the purpose of estimating the volume of playa lakes. Data were obtained from lakes that had been topographically mapped by the U. S. Geologic Service and some lakes were mapped in areas which did not already contain maps.

Cronin's data for the fine-textured soil area of an 1800 square mile portion of Castro, Swisher, Lamb, and Hale Counties gave area, depth, and volume relationships for 62 sample lakes.[2] Depth and volume data in other subareas of the High Plains were obtained by sampling lakes in each subarea. The topographically mapped portions of the North, Central, and South areas were divided into seven and one-half by nine mile rectangles. These rectangles were numbered and sampled at random to give ten sample rectangles from each of the North and Central areas and 10 sample rectangles from the South area. Eighteen lakes from each of these ten rectangles were surveyed. Topographic maps were constructed and lake volumes were computed. The volume of individual lakes was fixed at that quantity of water that could be contained below the lake's high water mark.[3] The surface areas and respective lake volumes for 18 lakes in the South area and 80 lakes in the North and Central areas were used in estimating the relationship between lake size and volume for various size lakes for each of the South and North-Central subareas.

The total lake storage volume of each subarea was estimated by using lake number and lake volume estimates. The quantity of water

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[2]Cronin, J. G., "A Summary of the Occurrence and Development of Ground Water in the Southern High Plains," Texas Board of Water Engineers, Austin, Texas, 1961.

[3]The high-water-mark volume was considered to be the lake's volume when full.

the lakes catch is a function of the number of times the lakes collect various volumes per unit time. Adequate data for determining filling frequencies were not available, thus assumptions of filling frequencies were necessary. The specific assumptions are presented in the text. They were based on observations of filling frequencies of lakes located on the Texas Technological College farms.

Modification Costs

There are a large number of possible combinations of modification types and sizes for various sized lakes. Two mosquito control modification models for each of four representative lake sizes (8, 15, 25, and 45 acres lakes) were selected for study. The two modification models were (1) a circular reservoir and (2) a rectangular pit. The modification construction costs were expressed as follows:

$$C_m = (X_{m1} + X_{m2}) X_{m3} \quad , (m = 1, \ldots, 4)$$

where:

C_m = construction costs of modification m

X_{m1} = number of cubic yards of soil moved for excavation of modification m

X_{m2} = number of cubic yards of soil moved for water diversion into modification excavation m

X_{m3} = price per cubic yard of soil moved for construction of modification m

The annual maintenance cost of each modification model was assumed at five percent of the modification construction cost.

Circular Reservoir

The circular reservoir is constructed by excavating a pit and using the excavated soil to build a dam around the pit. The total number of cubic yards moved for the excavation was determined by equating the sunken pit's excavated soil volume with the resulting dam's soil volume, and increasing these soil volumes until the resulting water storage of the circular reservoir had a surface area and a water storage volume, that equalled the high-water-mark-volume of the unmodified lake.

Since a portion of the water storage was at a higher elevation than the unmodified lake bottom elevation, a rainfall runoff diversion system was needed to channel the water into the reservoir. The system consisted of a diversion terrace and an inlet canal. The total number of cubic yards of soil moved for water diversion was the quantity of soil moved for the terrace plus the quantity moved to construct the elevated canal dykes leading from the diversion terrace to the reservoir.

The number of cubic yards of soil moved to construct the water diversion terrace was dependent upon the cross sectional area of the terrace and the terrace length. Estimates of the cross-sectional area were determined from the Engineering Handbook for Soil Conservation Work Units (1956) and was designed to carry maximum expected volumes of water at a velocity which would allow settling of suspended soil particles. The settling of soil particles in the diversion terrace channel was desirable since this decreases silting in the modification pit.

The number of cubic yards moved to construct the inlet canal was dependent upon the cross sectional areas of the two canal dykes and the distance between the elevated pit and the diversion terrace.

Rectangular Pit

The rectangular pit modification was constructed by excavating a rectangular pit at the low point of the lake bottom and distributing the excavated soil over the lake bottom. The number of cubic yards of soil moved for

for the modification equalled the desired volume of the modification; i.e., one cubic yard of soil removed created one cubic yard of water storage space.

Water diversion costs included the costs of constructing a formless flue to prevent erosion of the pit banks as the water entered the pit.[4] The flume would consist of a channeled entrance covered with four inches of asphalt. A part of the excavated soil would be used to construct an earthern levee around the perimeter of the lake to channel the runoff into the lake through the flume.

Earth Moving Costs

A representative price for moving soil was determined from records of past excavation costs and price quotations of local area commercial earth movers. The construction costs for the circular reservoir were constant per cubic yard of earth moved. The constant price per cubic yard was applicable for building the diversion terraces, dykes, and excavation work with dozers or scrapers for short haul distances. The construction cost for the rectangular pit modification were higher per cubic yard of earth moved, than for the circular reservoir since in constructing the rectangular pit it was necessary to spread the excavated soil over the surrounding lake-bed.

Health Benefits to Modification

The annual health benefits were expressed as follows:

$$B = E_1 + E_2$$

where:

B = annual health benefits

E_1 = the annual medical expense of encephalitis

[4] A flume is an inclined channel for conveying water.

E_2 = the annual losses of income by encephalitis patients

Local area medical records on encephalitis patients and case medical cost data were used to estimate the direct medical costs of encephalitis. Direct medical costs included the initial medical costs incurred with the onset of the disease and the medical costs of the disease aftereffects. The annual direct medical cost of encephalitis was estimated by the following formula:

$$DC = (NC_1) + (NC_2)$$

where:

DC = annual direct medical costs of encephalitis

N = area average annual number of patients

C_1 = medical costs per patient

C_2 = average cost of tests for aftereffects.

The annual indirect costs of encephalitis were the costs to society of caring for patients mentally retarded from encephalitis and the dollar value of the income losses of encephalitis patients. The income losses due to encephalitis involved four categories of encephalitis patients: (1) persons regularly employed but tempirarily prevented from working, (2) housewives prevented from performing housework (3) persons permanently disabled by encephalitis, and (4) patients who succumbed to the disease.

The national mean annual earnings of full-time, year-round, paid civilian workers by age and sex were used along with study area age, and sex data in estimating incomes losses from encephalitis. Available local area income data were inadequate to permit a more refined local area estimate.

The following calculating procedures were used:

$$I_1 = \frac{D \; N \; P_1 \; P_2 \; E}{A}$$

where:

I_1 = annual income losses by males temporarily absent from work

D = the average number of days of disability per case

N = average annual number of cases in the study area

P_1 = percent of area average annual number of cases temporarily absent from work

P_2 = percent of N which were 14 years of age or older and were males

E = national mean annual earnings for all males 14 years of age or older

A = number of days in the year (365)

$$I_2 = \frac{D \; N \; P_1 \; P_2 \; E}{A}$$

where:

I_2 = annual income losses by females temporarily absent from work

D, N, P_1, and A are same as definitions presented above

P_1 = percent of area total annual number of cases temporarily absent from work

P_2 = percent of N that were 14 years of age or older and were females

E = national mean annual earnings for all females who were 14 years of age or older (housewives included).

Case severity data from Public Health Service publications were used to determine cases resulting in permanent disability. Incomes of deceased encephalitis patients were estimated from Public Health Service death reports. The present value of future incomes was adjusted

with life expectancy tables and labor participation rates. The deceased's foregone consumption was disregarded because the human consumption of products was considered an end in the creation of products with the death of a person being considered an economic loss to society.[5]

The computational procedure for estimating income losses of disabled and deceased cases was as follows:

$$I_{3,4} = \frac{\sum_{j=1}^{85} N_{mj} V_{mj} + \sum_{j=1}^{85} N_{fj} V_{fj}}{3P}$$

where:

$I_{3,4}$ = the present value of the future income of deceased and severely brain-damaged persons in the study area,

N_{mj} = the annual number of deceased and severely brain damaged males of age j,

V_{mj} = present value of future income losses of deceased and severly brain-damaged males at age j,

N_{fj} = the annual number of deceased and severely brain damaged females of age j,

V_{fj} = present value of future income losses of deceased and severely brain-damaged females at age j.

The annual indirect cost of potential encephalitis cases was expressed by the following formula:

$$IC = I_1 + I_2 + I_{3,4} + CM$$

where:

IC = annual indirect cost of encephalitis

I_1, I_2, $I_{3,4}$ defined as above.

C = annual cost of caring for mentally retarded encephalitis cases.

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[5] Public Health Service, Estimating the Cost of Illness, Health Economics Series No. 6, U. S. Dept. of Health, Education and Welfare, Public Health Service Publication No. 947-6, Washington, D. C., 1966.

M = number of cases of mentally retarded patients (M estimated constant at 10 cases per year).

The total health benefits from playa modification equal the sum of the direct and indirect costs of encephalitis attributable to playas. The encephalitis case records for each soil area were used to estimate the proportion of the foregone expense of encephalitis accruing to the fine-and the medium-textured soil areas. Estimated annual health benefits were utilized in the calculation of present value of the time stream of health benefits expected from playa modification projects. Present worth of future health benefits is stated as follows:

$$PW = \sum_{i=1}^{n} \frac{DC_i + IC_i}{(1 + r)^i}$$

where:

PW = present worth of the estimated health benefits stream

DC_i = estimated direct medical costs of encephalitis in year i

IC_i = estimated indirect costs of encephalitis in year i

r = annual discount rate

n = number of years of useful life of modification projects

Present worth was calculated at zero, and six percent discount rates.

Assumptions Underlying the Analysis

The major assumptions that were made in the analysis were as follows:

1. Playa lakes were symmetrical from the center.

2. The lake high-water mark characterized by vegetative debris, changing soil constitution, and changing nature and types of vegetation, was used to identify the surface size and the volume of the lake when full.

3. Five out of six years the lakes obtained an annual quantity of water equal to one high-water-mark volume, and one year out of six the lakes obtained a greater than high-water-mark volume of water.

4. An annual rainfall of greater than 25 inches resulted in the lakes obtaining a volume greater than the high-water-mark-volume.

5. Playa lakes were the source of 75 percent of Texas High Plains mosquitoes (Harmston, 1956).

6. An average of one brain-damaged encephalitis patient from the study area was admitted to a mental hospital every two years.

7. The average medical cost of the severely brain damaged encephalitis patients for the initial effects of the disease was two thousand dollars.

APPENDIX B

EMPLOYMENT AND INCOME

Appendix B

TABLE A — 1956 Labor Participation Rates*

Age Group	1956 Labor Force Participation Rates		1956 Unemployment Rates	
	Male	Female	Male	Female
Total	82.9	35.9	3.8	4.9
14-19	47.5	31.8	10.2	10.9
20-24	87.8	46.3	6.9	6.3
25-34	97.3	35.4	3.3	4.8
35-44	97.9	43.1	2.6	3.9
45-54	96.5	45.5	3.0	3.6
55-64	88.5	34.9	3.5	3.6
65+	40.0	10.8	3.5	2.3

*Public Health Service Publication #947-6 May 1966 p. 14, U. S. Dept. of Labor, Bureau of Labor Statistics, Labor Force, Employment and Employment Statistics, 1947-61. Oct. 1962.

Appendix B

TABLE B -- Final Adjusted Mean Annual Earnings in 1963 of Full-Time, Year-Round Paid Civilian Workers by Age and Sex, United States.*

Age Group	Male	Female
Mean total	6,949	4,027
14-19	2,582	3,411
20-24	4,435	3,464
25-29	6,181	3,802
30-34	7,074	4,350
35-39	7,655	4,178
40-44	7,869	4,347
45-49	7,569	4.473
50-54	7,179	4,243
55-59	6,805	4,247
60-64	6,973	4,351
65 and over	5,532	2,943

*Source: "Estimating the Cost of Illness" Health Economics Series #6, U. S. Dept. of HEW, Public Health Service Publication #947-6. Washington, D. C., May 1966, p. 14.

Appendix B

Table C -- Present Value of Lifetime Earnings: Amount Discounted at 4 Percent and 6 Percent, by Age and Sex, United States.[a]

Age	Males[b]		Females	
	4%	6%	4%	6%
Under 1	59,063	30,622	34,622	18,189
1-4	64,989	34,998	37,938	20,708
5-9	79,333	46,986	46,289	27,791
10-14	96,736	62,994	56,422	37,240
15-19	114,613	80,953	64,936	45,990
20-24	126,688	94,811	67,960	49,987
25-29	128,698	100,011	66,826	50,205
30-34	122,904	98,298	64,389	49,367
35-39	111,956	91,864	60,998	47,744
40-44	97,301	81,766	56,603	45,286
45-49	80,235	69,025	50,896	41,568
50-54	63,027	55,410	44,371	36,691
55-59	45,948	41,334	37,467	31,845
60-64	28,387	25,970	30,164	26,126
65-69	15,043	13,737	23,579	20,823
70-74	9,264	8,573	18,118	16,406
75-79	5,344	5,014	12,888	12,024
80-84	2,395	2,791	6,916	6,659
85 and over	210	205	1,123	1,096

[a] Source: "Estimating the Costs of Illness", Public Health Service, Pub. No. 947-6, Department of Health, Education and Welfare, Washington, D. C., May 1966, page 93.

[b] The present value of the future earnings of a male at age a is defined by the following formula:

$$V_a = \sum_{n=a}^{85 \text{ and over}} \frac{X_n W_n P_a^n}{(1+i)^{n-a}}$$

where:

a is the midyear age for the given cohort of persons

X_n is the annual mean earnings for all males with earnings in an age group where the midpoint is age n

i is the discount rate

Table C (continued)

$W_n P_a^n$ is defined as the number of labor force years per person in an age group and is determined as follows:

$$W_n P_a^n = \frac{\sum_{j=t}^{t+r-1} L_j W_j}{L_a}$$

where:

j is the single year of age under consideration

t is the beginning year of the age group

r is the number of years in this age group; in any age group j can go from t to t + r - 1

L_j is the number of males surviving to j out of a cohort of 100,000 live male births, based on 1960 Life Tables, National Office of Vital Statistics

W_j is the single year labor force participation rate

L_a is the number of persons living at the midyear age a for the given single subgroup out of a cohort of 100,000 live male births

P_a^n is the approximate probability that a male age a survives to n

W_n is the average labor force participation rate in the age group with midyear age n, resulting from the single year labor force participation rates W_j.